Lebensm.-Wiss. u.-Technol., 34, 424–429 (2001)

# Co-extrusion of Dietary Fiber and Milk Proteins in Expanded Corn Products

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*(Received July 21, 1999; accepted December 11, 2000)*

*To improve the nutrient-density of snack products, milk proteins (casein, whey protein concentrate or whey protein isolate) and wheat fiber were co-extruded with corn meal flour, in a twin screw extruder under high shear and high temperature processing conditions. Co-extruding corn products and fiber resulted in the reduction of specific mechanical energy while increasing the expansion and breaking strength of the extrudate. Fiber added at 125 g/kg increased expansion and breaking strength. Whey products alone, at a concentration of 250 g/kg reduced expansion and water absorption properties, but the incorporation of fiber reversed this effect and improved expansion. The negative textural indicators associated with the inclusion of whey products can be improved significantly by adding wheat bran fiber at 125 g/kg. Adding fiber, improved specific mechanical energy (SME) along with product quality characteristics.*



**Keywords:** corn; fiber; breaking strength; extrusion; expansion; whey products; water absorption; texture

## Introduction

Extrusion cooking of cereals is widely practiced (Martinez-Serna *et al.*, 1989; Anon, 1994; Onwulata *et al.*, 1998); extruded cereals command a significant share of the snack food market in the U.S. (Barres *et al.*, 1990). The nutrient density of snack foods has been low, and has stigmatized these products as 'junk' foods. Fortification with milk proteins to enhance nutritional quality has been limited due to adverse effects of protein supplementation in significant amounts (Lue *et al.*, 1991). Inclusion of whey proteins in significant quantities tends to reduce expansion, an important textural parameter (Lue *et al.*, 1991; Akdogan, 1996; Guha *et al.*, 1997). Adverse effects such as reduced expansion and increased bulk density have limited the amount of added whey protein to less than 100 g/kg product.

Cheese whey utilization within the United States is still below 60% of total production (Barres *et al.*, 1990). Incorporating whey into extruded products successfully will improve the nutritional profile of snacks, while increasing utilization of whey proteins. It has been reported that addition of small amounts of proteins from milk raffinate and non-fat dry milk ( $<$ 50 g/kg) enhances textural properties (Martinez-Serna & Villota, 1992), but to increase utilization significant amounts must be incorporated (Kirby *et al.*, 1989; Kollengode & Hanna, 1997).

The addition of fiber to extruded snacks has been limited to few fiber sources such as wheat and oat (Hsieh *et al.*, 1991), sugar beet fiber (Hsieh *et al.*, 1989) and soy fiber (Jin *et al.*, 1995). Sugar beet fiber included in significant amounts ( $>$ 100 g/kg) in products increased structural strength, but reduced expansion (AOAC, 1997). Increases in mechanical energy associated with increasing fiber do not translate to greater expansion or reduced specific bulk density, which are desirable snack characteristics (Guha *et al.*, 1997).

Composite foods with proteins and fiber provide a nutritional psycho-social beneficial quality that enhances acceptance of extruded foods. Combining wheat bran fiber and milk proteins (components that would ordinarily tend to reduce expansion), will result in desirable nutritional profiles and improvement in acceptance of snack products. Therefore, the purpose of this study was to determine the effect of fibers and milk proteins on extruded corn snack foods.

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0023-6438/01/070424 + 06 $35.00/0
doi:10.1006/fstl.2000.0742

**Table 1** Proximate composition of materials[a] (g/100 g)

| | Moisture | Protein | Fat | Ash | Carbohydrates |
|---|---|---|---|---|---|
| Corn meal | 12.0 | 9.0 | 2.0 | 0.7 | 76.3 |
| Wheat Bran | 5.0 | 17.2 | 4.5 | 7.5 | 65.8 |
| Casein Caseinate | 3.1 | 92.0 | 1.2 | 3.4 | 0.3 |
| WPC[b] | 6.0 | 78.7 | 4.3 | 4.0 | 7.0 |
| WI[c] | 4.0 | 93.6 | 0.5 | 1.6 | 0.5 |

[a]Approximate composition from manufacturer specifications on a wet basis.
[b]WPC Whey Protein Concentrate (ALACEN 856).
[c]WI Whey Protein Isolate (ALACEN 895). Calcium caseinate (ALANATE 391). New Zealand Milk Products, North America (Santa Rosa, CA).

## Materials and Methods

Stabilized red winter wheat bran was received from Canadian Harvest (Ontario, Canada), and milk proteins from New Zealand Milk Products, North America (Santa Rosa, CA, U.S.A.). Corn meal was purchased from a commercial supplier (J. M. Swank Co. North Liberty, IA, U.S.A.). Proximate compositions of the materials are presented in **Table 1**.

A Werner Pfleiderer ZSK-30 twin screw extruder (Werner Pfleiderer Co. Ramsey, NJ, U.S.A.) with smooth barrel was used to puff the products. The last three barrel temperatures were set at 100, 110 and 125 °C, respectively. The die was fitted with two circular inserts of 3.18 mm diameter each. The screw elements, including kneading blocks and reverse screw elements were selected to offer a high shear at 300 rpm. Feed was conveyed into the extruder with a K-tron series 6300 digital feeder, type T-35 twin screw volumetric feeder (K-tron Corp., Pitman, NJ, U.S.A.). The feed screw speed was set at 600 rpm. Water was added at a rate of 1.02 L/h with an electromagnetic dosing pump (Milton Roy, Acton, MA, U.S.A.). Samples were collected after 25 min of processing. The samples were dried in a laboratory oven set at 120 °C, for 5 min, and stored at 4.4 °C until analysed. The experimental design was a full factorial blocked by product type (amount of corn meal), and by the level of fiber. The blocks were completely randomized and replicated three times. Analysis of variance was used to identify differences in physical properties at various processing conditions. Duncan's multiple range test was used for mean separation, and correlation coefficients were calculated. The statistical analysis system (SAS) package was used (SAS Institute Inc, Cary, NC, U.S.A.) in all cases (Camire & King, 1991).

Radial expansions (mm) were determined with a digital Vernier caliper (Monostat Corp. Switzerland). Radial expansion was determined by averaging the diameter of 10 samples from each treatment. The expansion index (EI) was calculated by dividing extrudate diameter by die orifice diameter (3.18 mm).

Moisture was determined from extrudates dried for 15 min at $120 \pm 5$ °C. The moisture contents of the extrudates exiting the extruder ranged from 15 to 19% and were not significantly different ($P < 0.05$). Approximately 2 g of the extruded products were dried in a vacuum oven for 4 h at 100 °C, and moisture was reported as loss in weight (Grenus *et al.*, 1993).

Substance density of the ground extrudate was determined by an air pycnometer (Horiba Instruments Inc, Model VM 100, Irvine, CA, U.S.A.).

A TA-XT2 Texture Analyzer (Stable Micro Systems, Surrey, England), outfitted with a 500 N load cell, running at a cross-head speed of 0.2 mm/s, and fitted with a Warner-Bratzler shear cell (1 mm thick blade) was used to determine breaking strength. Breaking strength (kg) was determined by measuring the maximum force required to break the extruded samples ($\sim$50 mm) in the shear cell. Data reported are the averages of 10 tests.

Water absorption (WAI) and water solubility (WSI) indices were derived from an AACC method #56-20, as modified from Jin *et al.* (1995). Samples were ground and sifted through a 210 $\mu$m sieve. A 1.0 g $\pm$ 0.005 g sample was placed in a centrifuge tube, and 10 mL distilled water were added. After standing for 15 min (with intermittent shaking every 5 min), the samples were centrifuged for 15 min at $1000 \times g$ (Econospin Model, Sorvall Instruments, Wilmington, DE, U.S.A.). The supernatant was decanted, and the weight gain in the gel was noted. WAI was calculated as [(weight gain of the gel)/(dry weight)]. The supernatant was decanted into a tared aluminum pan. The supernatant was dried overnight under vacuum at 90 °C. Water solubility index was determined as [(weight of dried supernatant)/(weight of dry sample) 100].

Specific mechanical energy (SME) was calculated as the ratio of the extrusion process conditions (torque, rpm and feed flow rate), to the net energy input from the screw and shaft drive (Sokhey & Chinnaswamy, 1992).

## Results and Discussions

*Protein products*

The properties of corn products formulated with three different milk proteins, casein, whey protein concentrate, or whey isolates added at 250 g/kg are presented in **Table 2**. Moisture retention in extruded products varied significantly ($P < 0.05$) only with whey protein concentrate. Water absorption increased correspondingly with whey protein concentrate. Whey isolate reduced water absorption significantly ($P < 0.05$). Addition of WPC or

**Table 2** Properties of extruded corn and milk proteins added at 250 g/kg

| | | Corn (750 g/kg) | | |
|---|---|---|---|---|
| Products | Corn | Casein | WPC[a] | WI[b] |
| Moisture (g/100 g) | 6.2 b | 5.7 b | 9.8 a | 6.0 b |
| WAI[c] (g/100 g) | 4.7 ab | 4.7 ab | 5.2 a | 4.4 b |
| WSI[d] (g/100 g) | 20.6 a | 23.9 a | 15.0 b | 13.8 b |
| SME[e] (kJ/kg) | 270 a | 218 b | 133 d | 152 c |

[a]WPC: Whey protein concentrate.
[b]WI: Whey isolate.
[c]WAI: Water absorption index.
[d]WSI: Water solubility index.
[e]SME: Specific mechanical energy.
Pooled Standard Deviation: Moisture $\pm$2.6; WAI $\pm$0.4; WSI $\pm$ 3.1; SME $\pm$ 4.5.
Columns across with different letters are significantly different at $P < 0.05$ or 0.01.

**Table 3** Properties of extruded corn and fiber substituted at 50 and 125 g/kg

| | | Fiber | |
|---|---|---|---|
| Products | Corn | 50 g/kg | 125 g/kg |
| Moisture (g/100 g) | 6.2 ab | 5.6 c | 7.8 a |
| WAI[a] (g/100 g) | 4.7 a | 4.8 a | 4.7 a |
| WSI[b] (g/100 g) | 20.6 a | 15.9 b | 12.1 bc |
| SME[c] (kJ/kg) | 270 a | 268 a | 211 b |

[a]WAI: Water absorption index.
[b]WSI: Water solubility index.
[c]SME: Specific mechanical energy.
Pooled Standard Deviation: Moisture $\pm$2.6; WAI $\pm$0.4; WSI $\pm$ 3.1; SME $\pm$ 4.5.
Columns across with different letters are significantly different at $P < 0.05$ or 0.01.

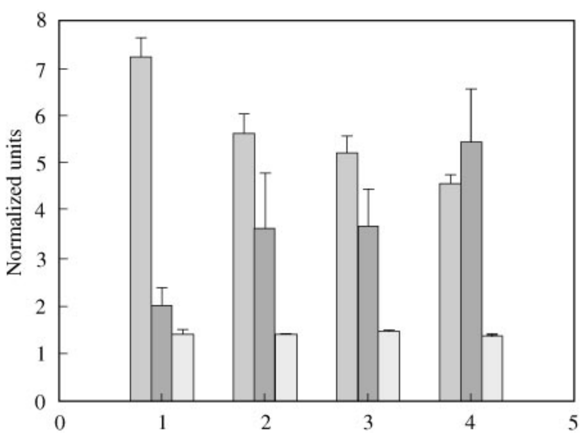


**Fig. 1** Extruded corn meal with milk protein substituted snack. (1) Corn; (2) Corn + Casein (250 g/kg); (3) Corn + WPC (250 g/kg); (4) Corn + WI (250 g/kg). ▢, Exp: Expansion (mm); ▢, BKS: Breaking strength (N); ▢, S-DEN: Substance density (kg/m$^3$)

WI reduced water solubility significantly. The casein substituted product was similar to the control in solubility. SME input into the extruder was reduced very significantly ($P < 0.01$) by all the proteins studied with corn > casein > WI > WPC in order. In maintaining torque and shear conditions near optimum with protein substituted products, casein is more desirable as it improves product characteristics. The effect of reduction in mechanical energy also is seen with extrudate expansion and breaking strength (**Fig. 1**); density was not changed. The large molecular structure of casein, hydrophobic properties and random coil conformation contributed in maintaining expansion. SME plays a significant role in product quality, though its correlation with product quality characteristics is generally in the range ($R^2 = 0.45$ to 0.85) for most processes (Kirby *et al*., 1989; Akdogan, 1996; Govindaswamy *et al*., 1997; Guha *et al*., 1997; Kollengode & Hanna, 1997). The addition of milk proteins did not change the product density significantly. This reduction is generally what happens with protein incorporation (Kim & Maga, 1997; Camire & King, 1991). However, we have shown, by changing extrusion conditions to effect increases in SME, especially by reducing moisture, that whey products can be incorporated up to 25 g/100 g. Earlier work showed that the addition of whey proteins to extruded products reduced expansion significantly (Kim & Maga, 1987; Martinez-Serna & Villota, 1992). Martinez-Serna and Villota (1992), reported a 30% decrease in expansion ratio due to changes in viscoelasticity during extrusion.

*Fiber products*

The effect of incorporating fiber at 50 g/kg and 125 g/kg respectively, into an extruded corn product is presented in **Table 3**. Fiber incorporation changed water retention in the product significantly ($P < 0.05$). Fiber added at 50 g/kg fiber reduced moisture content considerably. The level of fiber did not affect water absorption, but it affected product solubility (WSI) significantly ($P < 0.05$). Considering fiber substituted products alone, the water content of the product affected solubility; as water content increased, water solubility index decreased. The water properties tend to reflect product texture characteristics. The addition of fiber affected the process conditions as reflected by the SME. At 50 g/kg fiber, SME was similar to the control; however, at 125 g/kg, SME was reduced. This is reflected in the product qualities, expansion, breaking strength and density (**Fig. 2**). Density was not changed by the inclusion of fiber even at 125 g/kg; however, expansion was reduced and breaking strength increased. Considering expansion and breaking strength, adding fiber at 5 g/kg did not change product characteristics. Hsieh *et al.* (1989), reported no changes to SME due to the addition of fiber; however, they reported increases in temperatures at the die. Increase in temperature suggests reduction in viscosity which ultimately leads to reduced SME. Jin *et al.* (1995), reported the effect of fiber on SME to be non linear, depending on screw speed. This explains why SME was similar to the control at 50 g/kg fiber substitution, and lower at 125 g/kg fiber. Reduced expansion and increased breaking strength are characteristics of fiber substituted products resulting

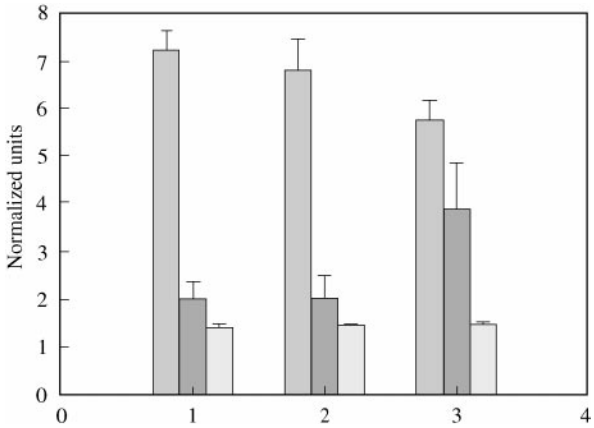


**Fig. 2** Extruded corn meal with wheat fiber substituted snack. (1) Corn; (2) Corn + Fiber (50 g/kg); (3) Corn + Fiber (125 g/kg). ▢, Exp: Expansion (mm); ▢, BKS: Breaking strength (N); ▢, S-DEN: Substance density (kg/m$^3$)

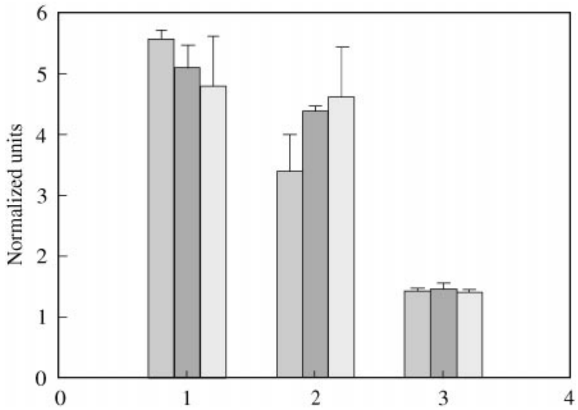


**Fig. 3** Extruded corn meal with milk proteins and wheat fiber substituted snack. (1) Corn + Casein (250 g/kg) + Fiber (50 g/kg); (2) Corn + WPC (250 g/kg) + Fiber (50 g/kg); (3) Corn + WI (250 g/kg) + Fiber (50 g/kg). ▢, Exp: Expansion (mm); ▢, BKS: Breaking strength (N); ▢, S-DEN: Substance density (kg/m$^3$)

**Table 4** Properties of extruded corn, fiber (50 g/kg) and milk proteins at 250 g/kg

| | | Corn (700 g/kg) and fiber (50 g/kg) | | |
|---|---|---|---|---|
| Products | Corn | Casein | WPC[a] | WI[b] |
| Moisture (g/100 g) | 6.2 b | 6.5 ab | 9.7 a | 8.1 ab |
| WAI[c] (g/100 g) | 4.7 ab | 4.7 ab | 4.8 a | 4.5 b |
| WSI[d] (g/100 g) | 20.6 a | 21.2 a | 13.8 b | 14.3 b |
| SME[e] (kJ/kg) | 270 a | 211 a | 152 b | 161 b |

[a]WPC: Whey Protein Concentrate.
[b]WI: Whey Isolate.
[c]WAI: Water absorption index.
[d]WSI: Water solubility index.
[e]SME: Specific mechanical energy.
Pooled Standard Deviation: Moisture ± 2.6; WAI ± 0.4; WSI ± 3.1; SME ± 4.5;
Columns across with different letters are significantly different at $P < 0.05$ or 0.01.

**Table 5** Properties of extruded corn, fiber (125 g/kg) and milk proteins at 250 g/kg

| | | Corn (700 g/kg) and fiber (125 g/kg) | | |
|---|---|---|---|---|
| Products | Corn | Casein | WPC[a] | WI[b] |
| Moisture (g/100 g) | 6.2 b | 8.1 b | 12.5 a | 6.9 b |
| WAI[c] (g/100 g) | 4.7 ab | 4.4 b | 4.9 a | 4.3 b |
| WSI[d] (g/100 g) | 20.6 a | 16.1 a | 10.5 b | 12.6 b |
| SME[e] (kJ/kg) | 270 a | 193 a | 132 b | 180 a |

[a]WPC: Whey Protein Concentrate.
[b]WI: Whey Isolate.
[c]WAI: Water absorption index.
[d]WSI: Water solubility index.
[e]SME: Specific mechanical energy.
Pooled Standard Deviation: Moisture ± 2.6; WAI ± 0.4; WSI ± 3.1; SME ± 4.5.
Columns across with different letters are significantly different at $P < 0.05$ or 0.01.

from reduced elasticity due to the presence of fiber (Hsieh *et al.*, 1991; Breen *et al.*, 1997).

*Fiber-protein interactions*

The interaction of 50 g/kg and 125 g/kg fiber, 250 g/kg milk proteins and 700 or 625 g/kg corn meal is presented in **Table 4**. Whey protein concentrate products were higher in moisture than whey isolate than casein in order. Water absorption varied with WI products absorbing the least amount of water. Casein products were significantly ($P < 0.01$) more soluble either WPC or WI products. Differences in water properties may reflect the level of entanglement and matrix formation with the corn meal. Casein (250 g/kg) and fiber (50 g/kg) required more work as indicated by significant ($P < 0.05$) SME values. Product characteristics (**Fig. 3**), show higher values for casein in expansion, breaking strength and density. Whey protein products were not as high as casein; however, whey isolate product characteristics were significantly ($P < 0.01$) reduced. Considering SME and known product behavior, it can be concluded that significant intra molecular interactions was occurring with whey isolate products, even with fiber added at 50 g/kg.

The result of increasing the amount of fiber to 125 g/kg is presented in **Table 5**. WPC retained the most water in the product, and was the highest in water absorption index and absorbed the most water ($P < 0.05$). The casein product was the most soluble, while WPC and WI products were similar. However, in the specific mechanical energy work input, the addition of fiber at 125 g/kg increased the work in the whey isolate products to be equivalent to that of casein. Whey protein concentrate was significantly lower ($P < 0.05$). This reversal is evident from the product characteristics shown in **Fig. 4**. Density of products was not affected, expansion did not vary with type of milk protein, but breaking strength increased with WI products being the largest. There was a

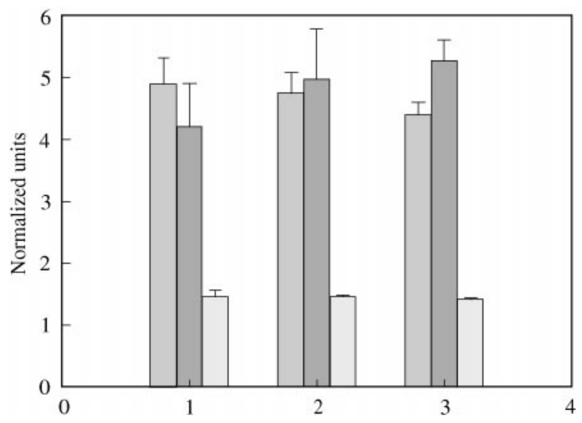


**Fig. 4** Extruded corn meal with milk proteins and wheat fiber substituted snack. (1) Corn + Casein (250 g/kg) + Fiber (125 g/kg); (2) Corn + WPC (250 g/kg) + Fiber (125 g/kg); (3) Corn + WI (250 g/kg) + Fiber (125 g/kg). ▥, Exp: Expansion (mm); ▥, BKS: Breaking strength (N); □, S-DEN: Substance density (kg/m$^3$)

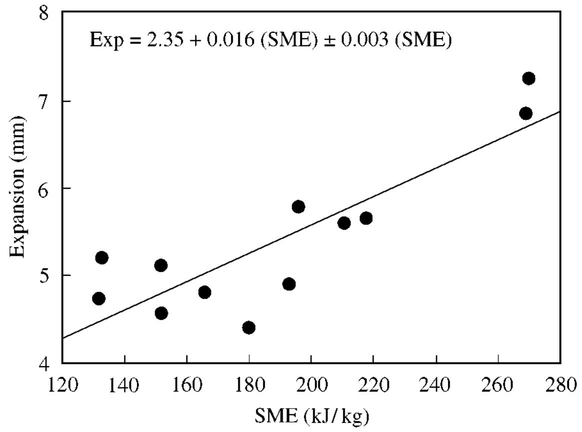


**Fig. 5** Relationship between SME and extruded corn substituted with milk protein and Fiber. Linear regression of SME to expansion. ●, Experimental; ——, Model.

significant interaction between protein and fibers ($P < 0.05$). The amount of fiber added makes a difference, along with the type of milk protein. This results from increased shear, which increases temperature (Hsieh *et al*., 1989), reduces viscoelasticity, and decreases SME. Specific mechanical energy is an indicator of product quality characteristics, in controlling for expansion and breaking strength. SME has shown high correlation with expansion (Matthey & Hanna 1997). In comparing the SME and expansion of the extruded protein and fiber products (**Fig. 5**), it is shown that moderate correlation is possible ($r^2 = 0.72$). Specific methods of increasing SME such as reducing the amount of water during extrusion and even going to higher fiber content could improve the SME produce a desirable product (Sokhey *et al*., 1994; Onwulata *et al*., 1998).

## Conclusion

Nutrient density of extruded snacks can be improved through inclusion of milk proteins and fiber. However, definitive process modification is needed to counter significant interactions resulting from three competing reactions, shear-work, protein and fiber, as well as the corn starches.


## Acknowledgments

The assistance of Mr Richard Stoler with product analysis is appreciated.


## References


Akdogan, H. Pressure, Torque, and energy responses of a twin screw extruder at high moisture contents. *Food Research International*, **29**, 423–429 (1996)

Anon. *Whey products utilization and production trends*. American Dairy Products Institute, Chicago, IL, (1994)

Aoac. *Official Methods of Analysis*, 16th Ed. Association of Official Analytical Chemists, Washington, DC, (1997)

Barres, C., Vergnes, B., Tayeb, J., Della Valle, G. Transformation of wheat flour by extrusion cooking: influence of screw configuration and operating conditions. *Cereal Chemistry*, **67**, 427–433 (1990)

Breen, M. D., Seyam, A. A. and Banasik, D. J. The effect of mill by-products and soy protein on the physical characteristics of expanded snack foods. *Cereal Chemistry*, **54**, 728–736 (1997)

Camire, M. E. and King, C. C. Protein and fiber supplementation effects on extruded corn meal snack. *Journal of Food Science*, **56**, 760–763, 768 (1991)

Della Valle, G., Boche, Y., Colonna, P. and Vergnes, B. The extrusion behaviour of potato starch. *Carbohydrate Polymers*, **28**, 255–264 (1995)

Govindasamy, S., Campanella, O. H. and Oates, C. G. High moisture twin screw extrusion of sage starch. 2. Saccharification as influenced by thermomechanical history. *Carbohydrate Polymers*, **32**, 267–274 (1997)

Grenus, K. M., Hsieh, F. and Huff, H. E. Extrusion and extrudate properties of rice flour. *Journal of Food Engineering*, **18**, 229–245 (1993)

Guha, M., Ali, S. Z. and Bhattacharya, S. Twin-screw extrusion of rice flour without a die - effect of barrel temperature and screw speed on extrusion and extrudate characteristics. *Journal of Food Engineering*, **32**, 251–267 (1997)

Hsieh, F., Huff, H. E., Lue, S. and Stringer, L. Twin-screw extrusion of sugar beet fiber and corn meal. *Lebensmittel-Wissenschaft und-Technologie*, **24**, 495–500 (1991)

Hsieh, F., Mulvaney, S. J., Huff, H. E., Lue, S. and Brent, J. Jr. Effect of dietary fiber and screw speed on some extrusion processing and product variables. *Lebensmittel-Wissenschaft und-Technologie*, **22**, 204–207 (1989)

Jin, Z., Hsieh, F. and Huff, H. E. Effects of soy fiber, salt, sugar and screw speed on physical properties and microstructure of corn meal extrudate. *Journal of Cereal Science*, **22**, 185–194 (1995)

Kim, C. H. and Maga, J. A. Properties of extruded whey protein concentrate and cereal flour blends. *Lebensmittel-Wissenschaft und-Technologie*, **20**, 311–318 (1987)

Kirby, A. R., Ollett, A. L., Parker, R. and Smith, A. C. An experimental study of twin screw configuration effects in the twin-screw extrusion-cooking of maize grits. *Journal of Food Engineering*, **8**, 247–272 (1989)

Kollengode, A. N. R. and Hanna, M. A. Cyclodextrin complexed flavors retention in extruded starches. *Journal of Food Science*, **62**, 1057–1060 (1997)

Lue, S., Hsieh, F. and Huff, H. E. Extrusion cooking of corn meal and sugar beet fiber: Effects on expansion properties, starch gelatinization, and dietary fiber content. *Cereal Chemistry*, **68**, 227–234 (1991)

MARTINEZ-SERNA, M. D. AND VILLOTA, R. Reactivity, functionality, and extrusion performance of native and chemically modified whey. In: KOKINI, J. L., HO, C. AND KARWE, M. V. (Eds). *Food Extrusion Science and Technology*. New York, NY. Marcel Dekker, Inc., pp. 387–414 (1992)

MARTINEZ–SERNA, M. D., HAWKES, J. AND VILLOTA, R. Extrusion of natural and modified whey proteins in starch-based systems. In: SPIESS, W. E. L. AND SCHUBERT, H. (Eds). *Engineering and Food, Advanced Processes*. New York, NY, Elsevier Applied Science. Vol. 3, pp. 346–365 (1989)

MATTHEY, F. P. AND HANNA, M. A. Physical and functional properties of twin-screw extruded whey protein concentrate — corn starch blends. *Lebensmittel-Wissenschaft & Technologie*, **30**, 359–366 (1997)

ONWULATA, C. I. AND HEYMANN, H. Sensory properties of extruded cornmeal related to the spatial distribution of process conditions. *Journal of Sensory Studies*, **9**, 101–112 (1994)

ONWULATA, C. I., KONSTANCE, R. P., SMITH, P. W. AND HOLSINGER, V. H. Physical properties of extruded products as affected by cheese whey. *Journal of Food Science*, **63**, 814–818 (1998)

SAS. *SAS/STAT User's Guide*, *Version* 6, 4th Edition. Statistical Analysis Systems Institute Inc., Cary, NC, U.S.A. (1996)

SINGH, R. K., NIELSEN, S. S., CHAMBERS, J. V., MARTINEZ-SERNA, M. AND VILLOTA, R. Selected characteristics of extruded blends of milk protein raffenate or nonfat dry milk with corn flour. *Journal of Food Protection & Preservation*, **15**, 285–302 (1991)

SOKHEY, A. S. AND CHINNASWAMY, R. Physicochemical properties of irradiation modified starch extrudates. *Food Structure*, **11**, 361–365 (1992)

SOKHEY, A. S., KOLLENGODE, A. N. AND HANNA, M. A. Screw configuration effects on corn starch expansion during extrusion. *Journal of Food Science*, **59**, 895–898, 908 (1994)